Identification of actuation manifolds in wall-bounded turbulent flows with active control

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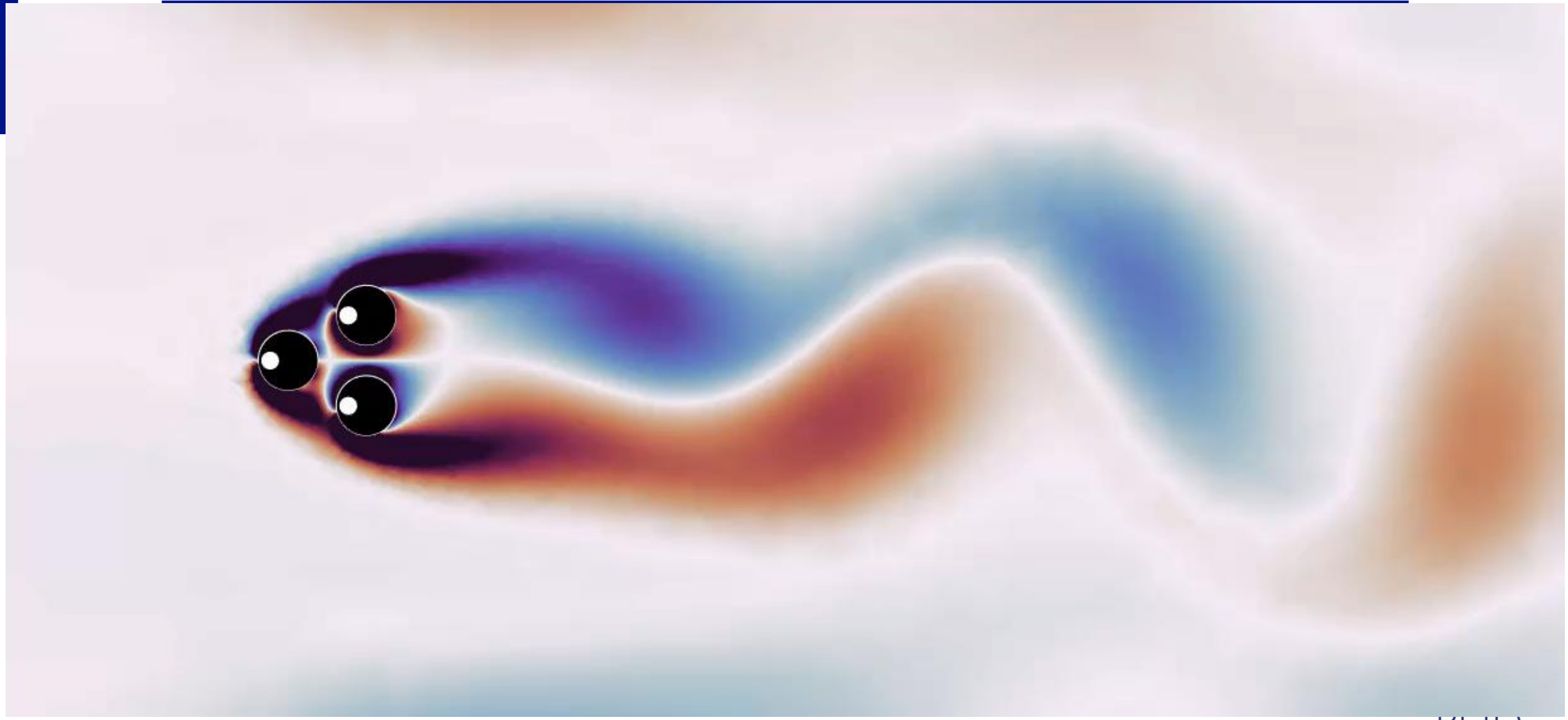
Advisors: Andrea Ianiro, Stefano Discetti

PhD Aerospace Engineering Doctoral Meeting 2025

uc3m

PHD

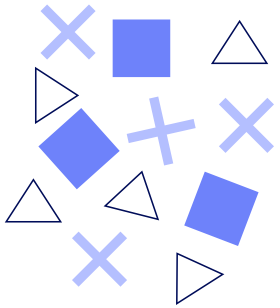
Aero space

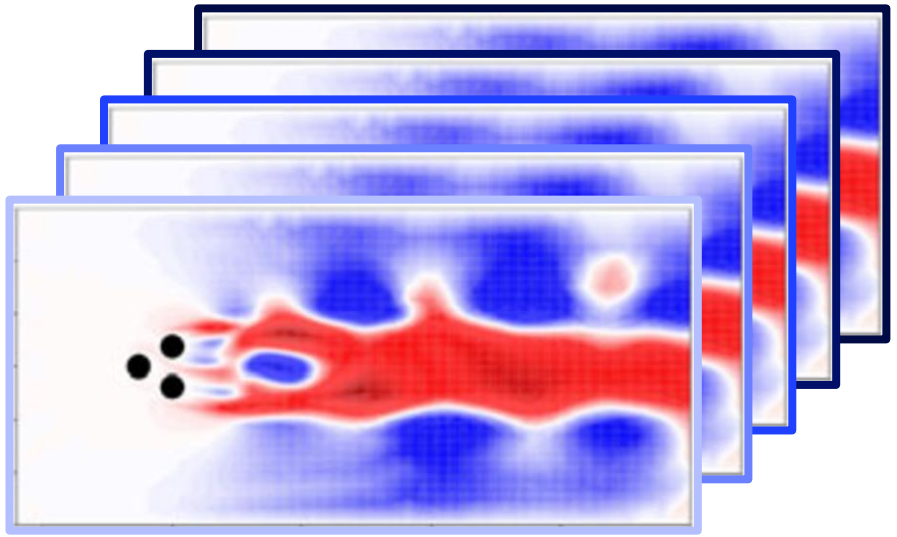


PHD

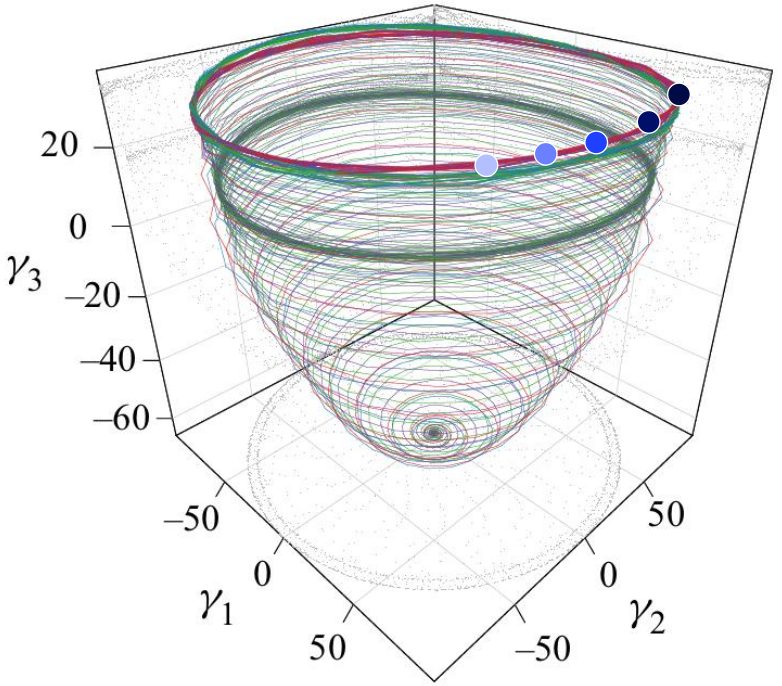
What are manifolds?

Input raw data





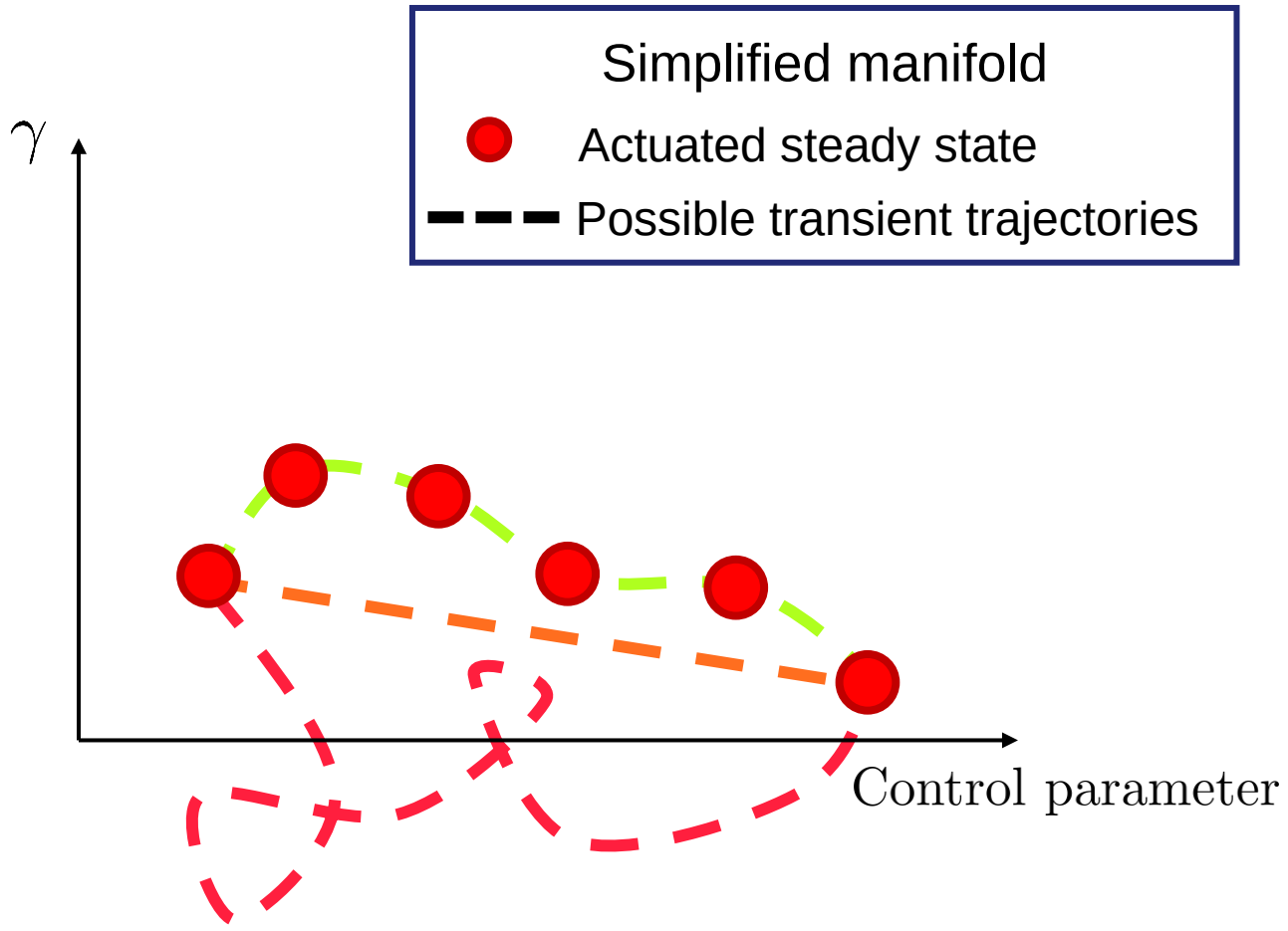
Manifold



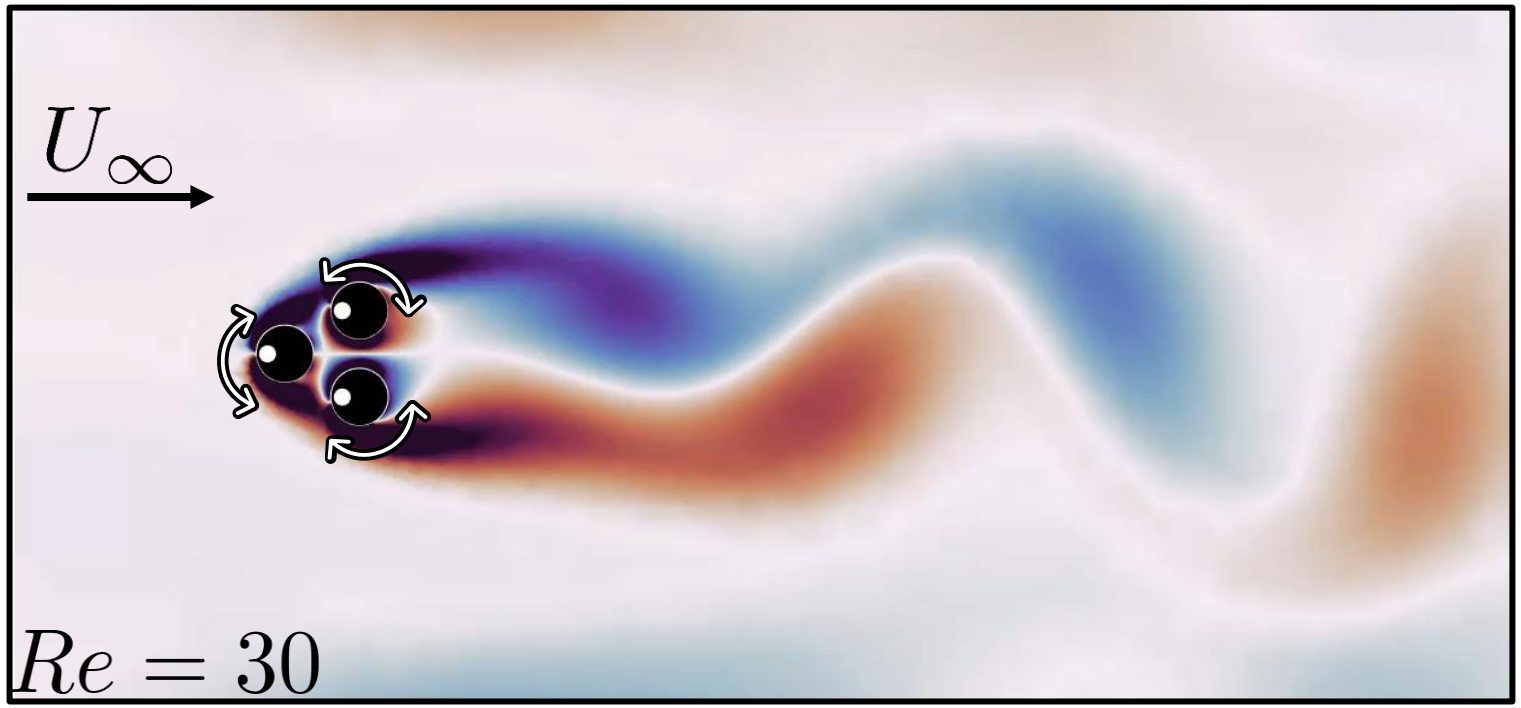
Farzamnik, E., Ianiro, A., Discetti, S., Deng, N., Oberleithner, K., Noack, B. R., and Guerrero, V. (2023). From snapshots to manifolds–a tale of shear flows. J. Fluid Mech., 955:A34.

Motivation

- **Why manifolds?**
  - We need reduced-order models
- **Why actuated?**
  - To build control-oriented model
- **Challenge?**
  - Include the transient effects



Test case: The fluidic pinball

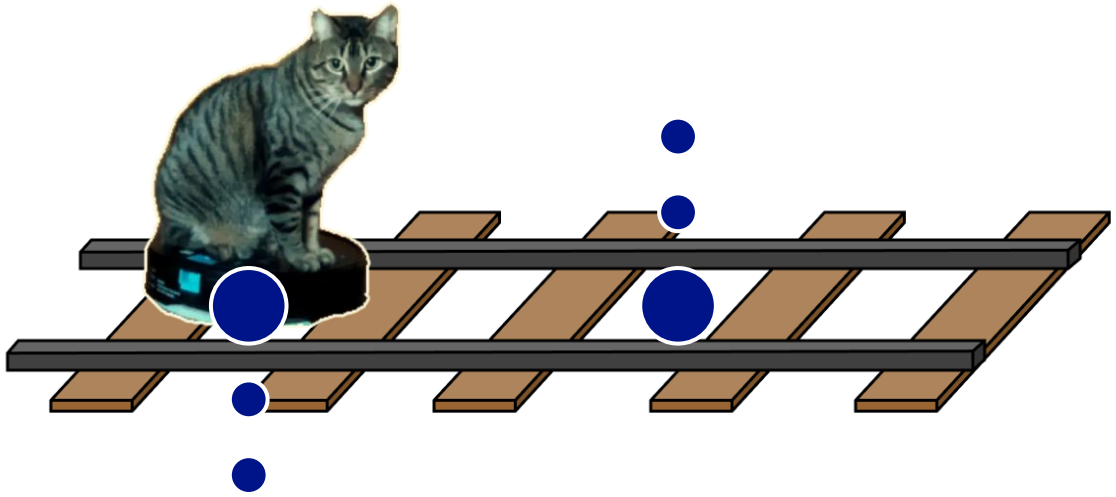


- Bifurcations
- 6 actuation mechanisms

Encapsulates the main features of wake flows

What I have done in my ongoing PhD journey

Comparative analysis of manifold learning techniques



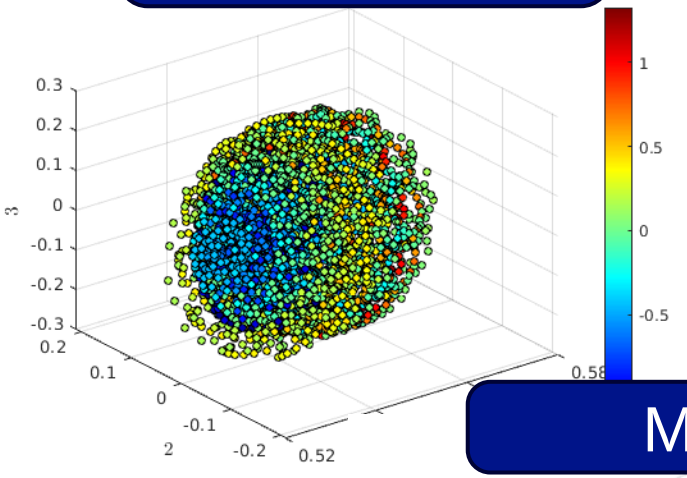
Literature review

- Manifold learning
- Data-driven methods

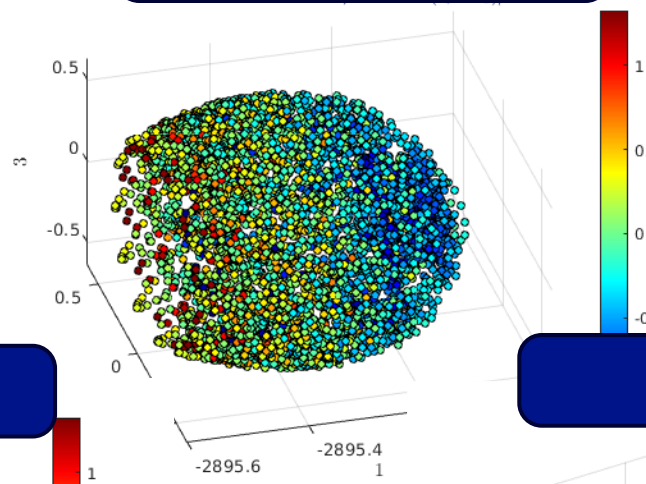
Comparative analysis of manifold learning techniques

Development of manifold learning codes

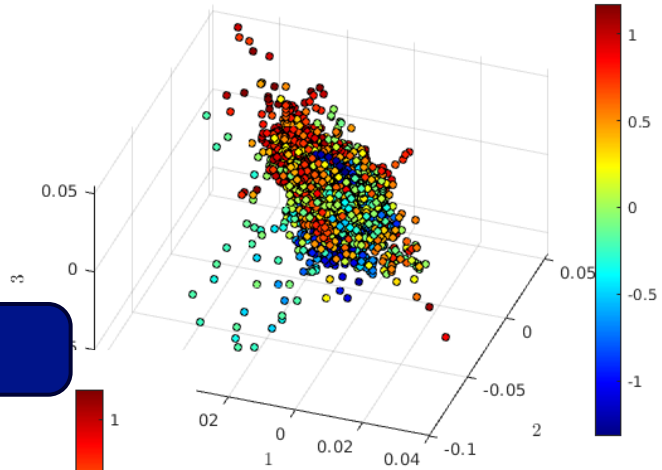
PCA



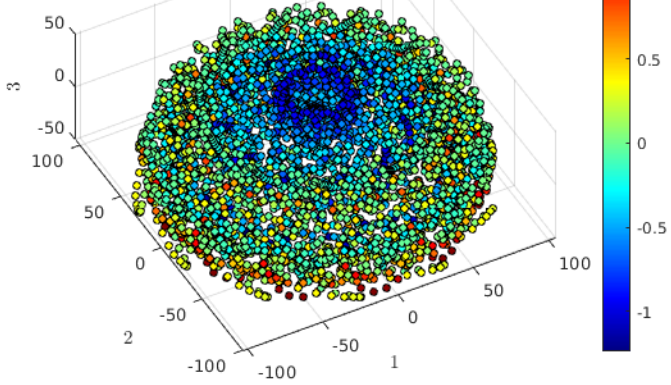
kPCA



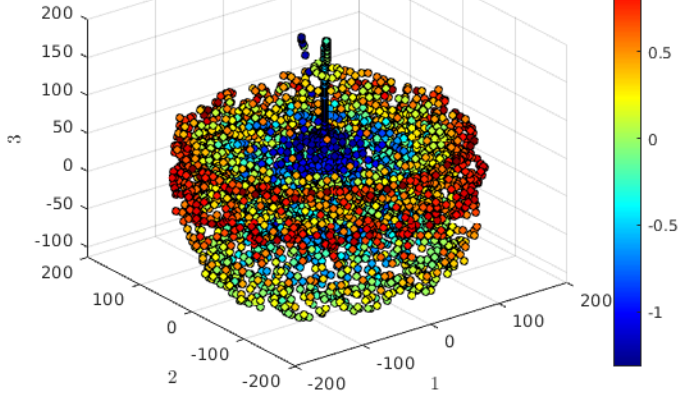
LLE



MDS



ISOMAP



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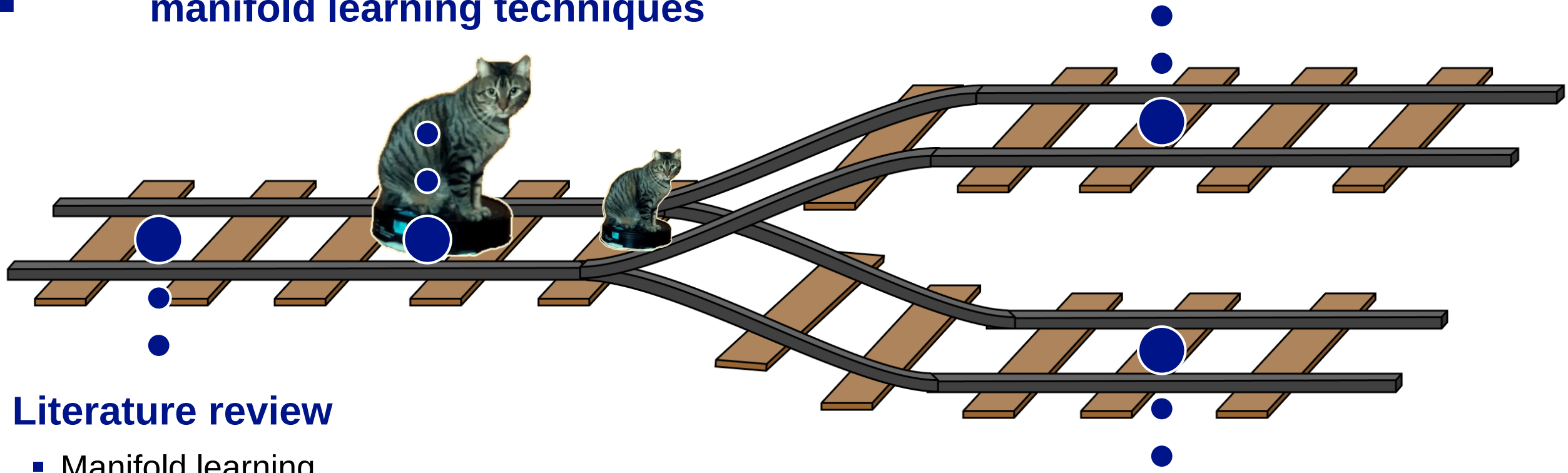
Analysis & modelling of the fluidic pinball under time-varying actuation



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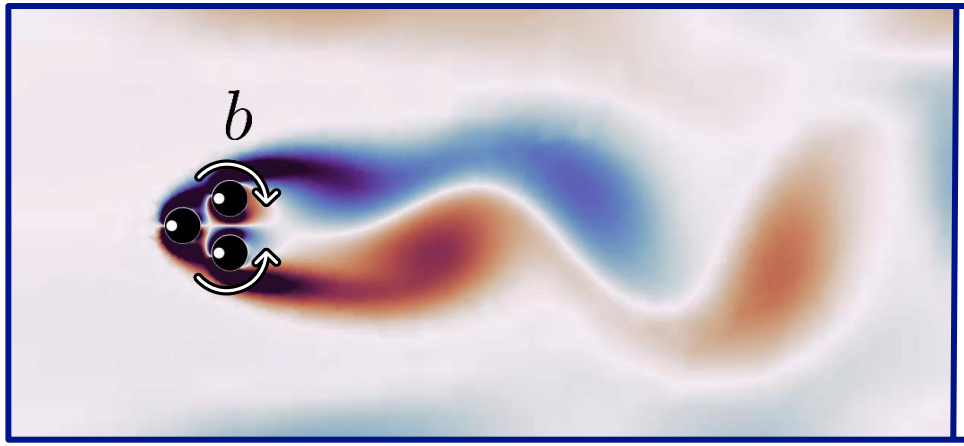
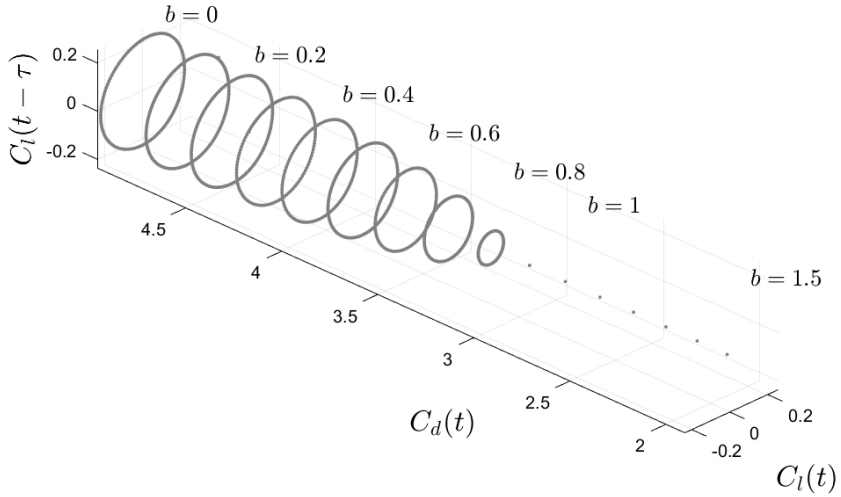
Fluidic pinball experiment

Analysis & modelling of the fluidic pinball under time-varying actuation



$$\mathbf{q} = \begin{bmatrix} C_l(t) \\ C_l(t-\tau) \\ C_d(t) \end{bmatrix}$$

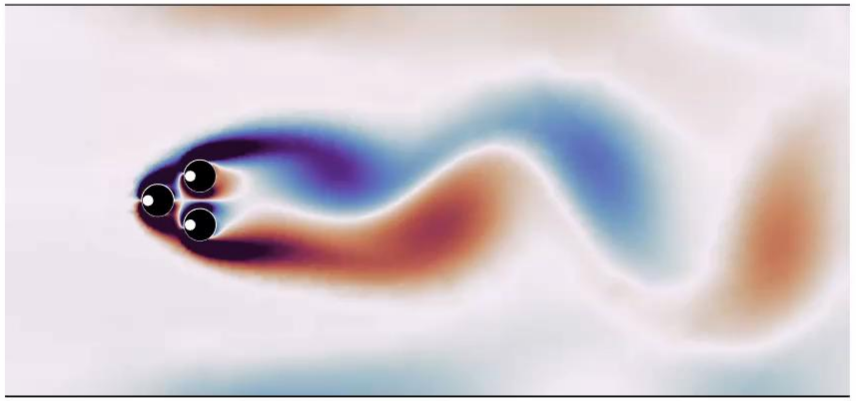
$$\dot{\mathbf{q}} = \mathrm{f}(\mathbf{q}, b)$$

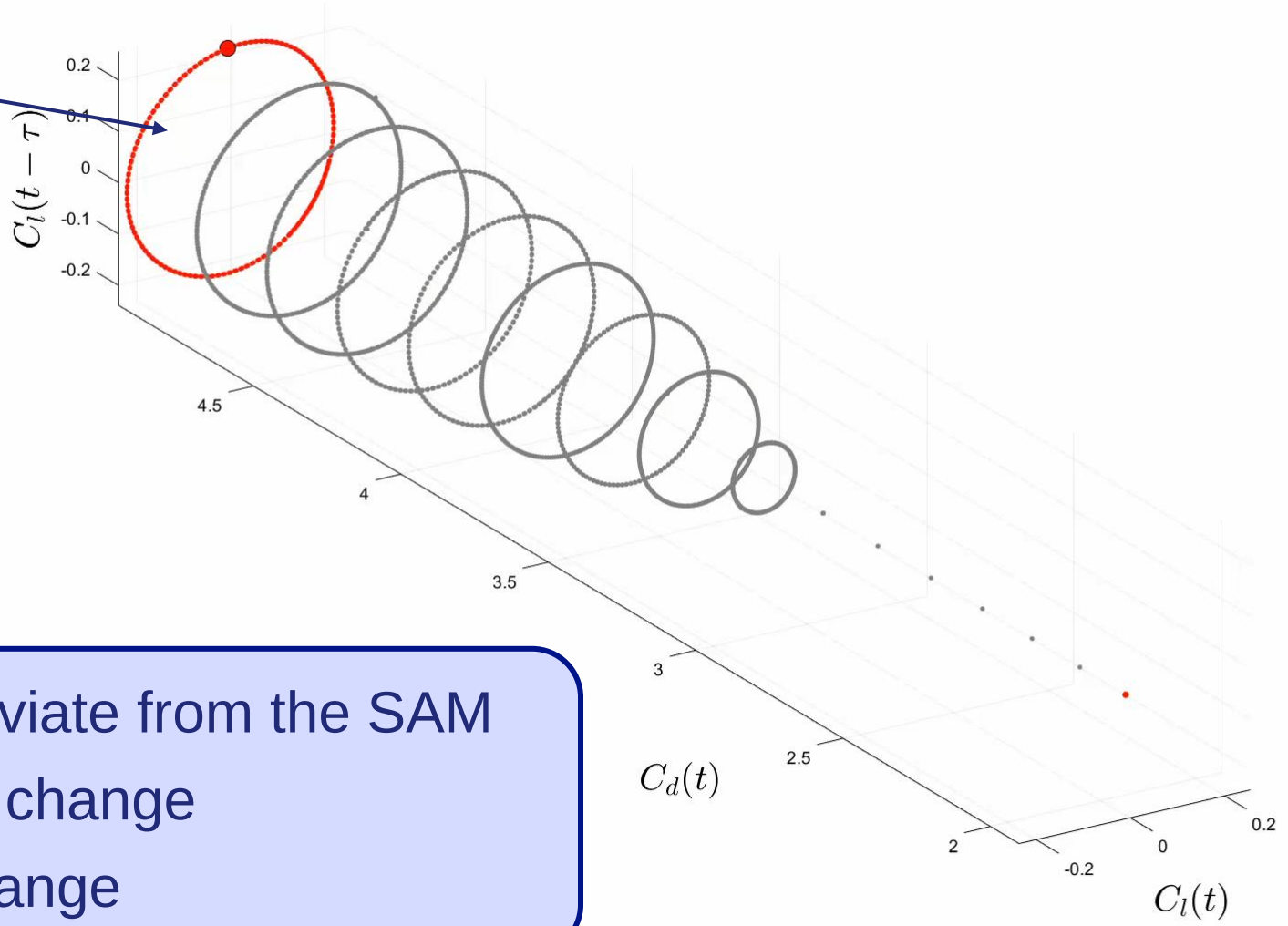


b

Analysis & modelling of the fluidic pinball under time-varying actuation

Change in 10 periods $\left(\frac{\mathrm{d}b}{\mathrm{d}t} = 0.15\right)$

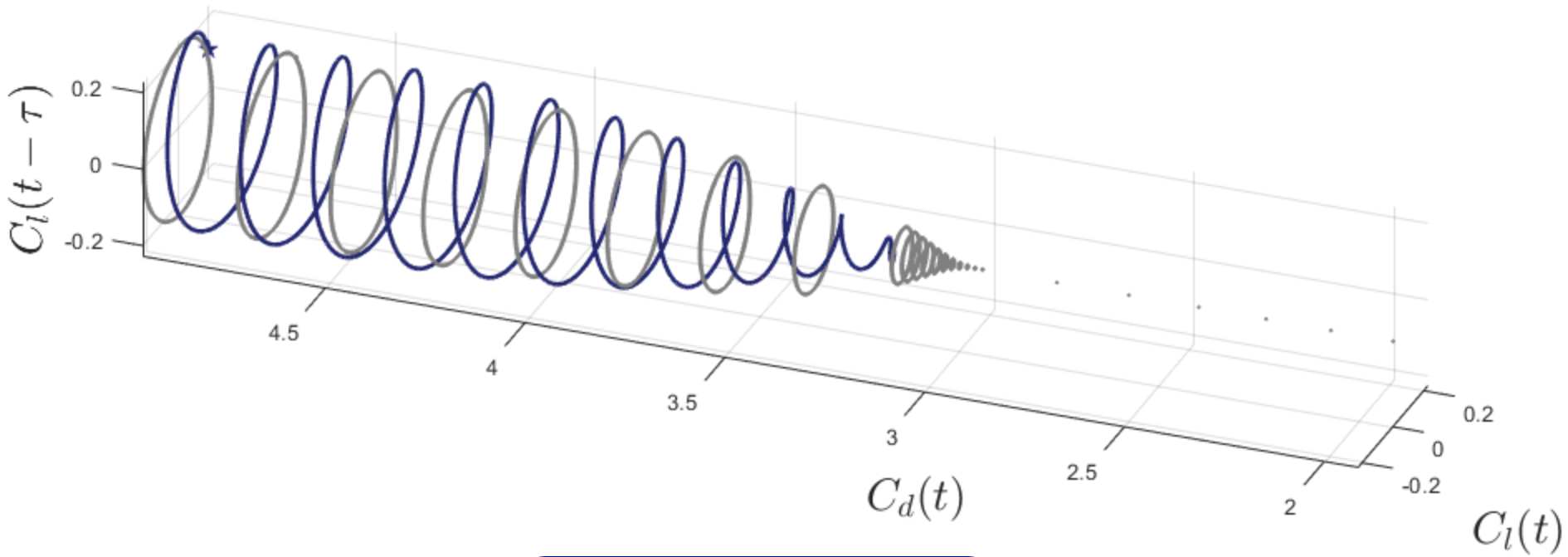




Fast control trajectories deviate from the SAM

- Magnitude of change
- Rate of change

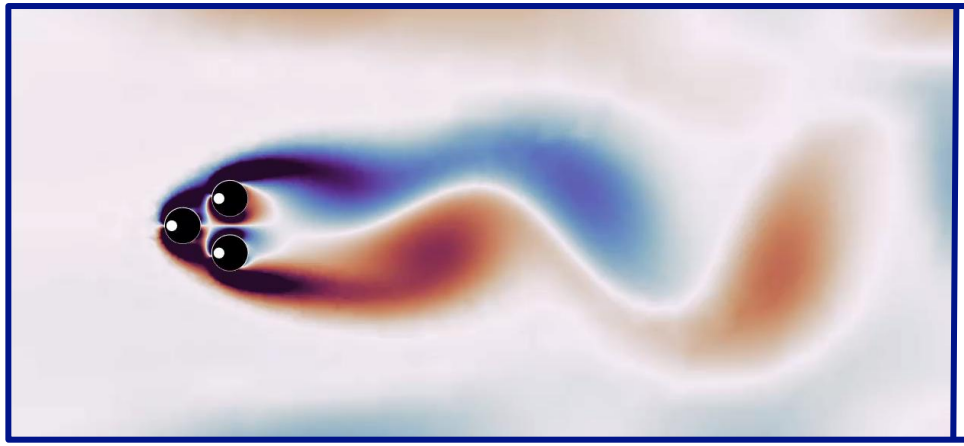
Analysis & modelling of the fluidic pinball under time-varying actuation



$$\tilde{b} = \beta b \rightarrow \beta = \frac{\tilde{b}}{b}$$

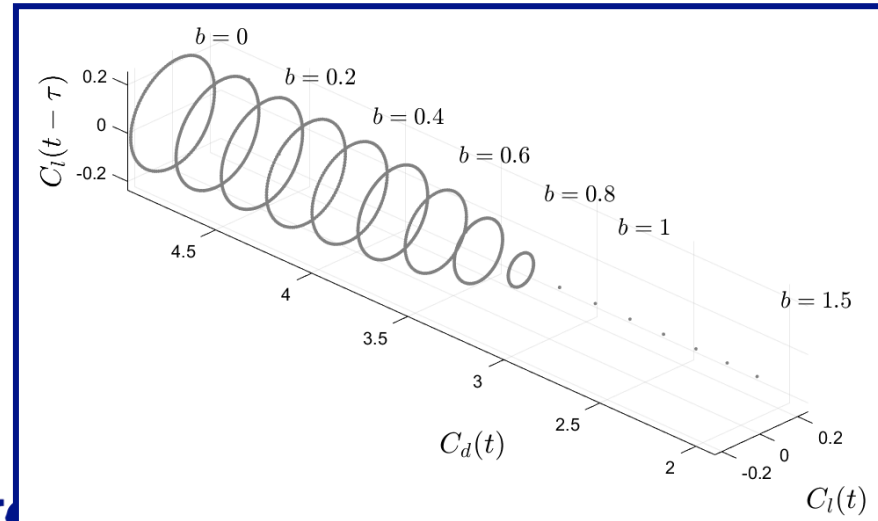
Fitting parameter β

Analysis & modelling of the fluidic pinball under time-varying actuation



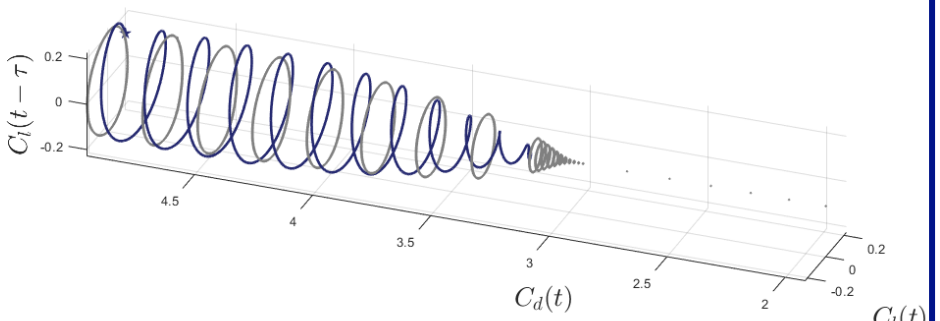
$$\mathbf{q} = \begin{bmatrix} C_l(t) \\ C_l(t-\tau) \\ C_d(t) \end{bmatrix}$$

$$\dot{\mathbf{q}} = f(\mathbf{q}, b, \frac{\mathrm{d}b}{\mathrm{d}t})$$



b

$\frac{\mathrm{d}b}{\mathrm{d}t}$



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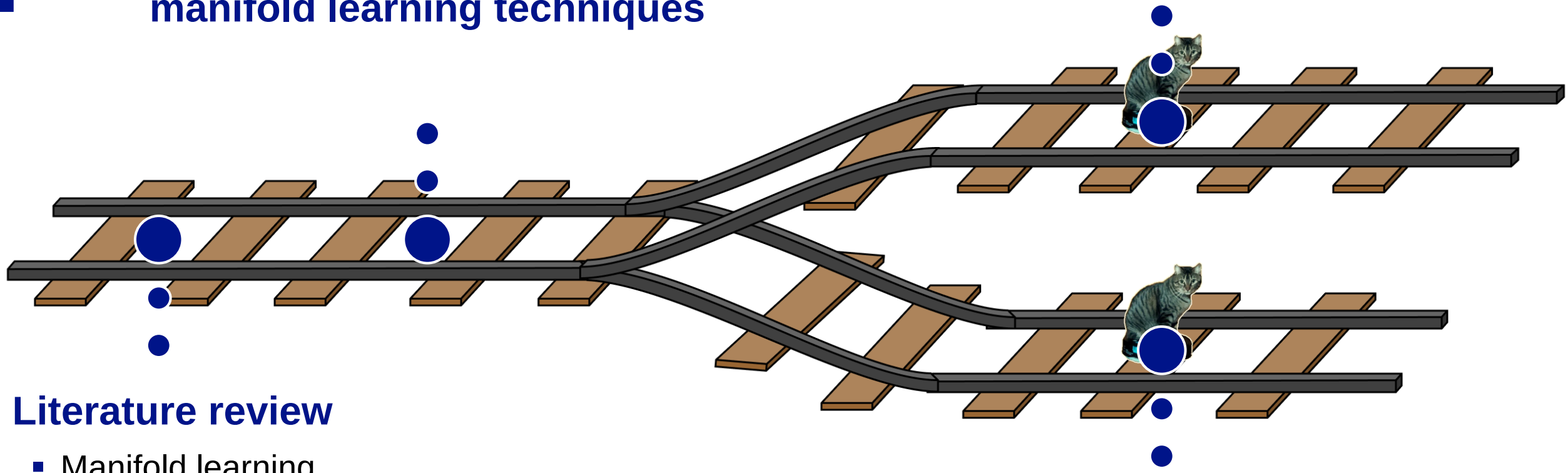

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Fluidic pinball experiment

Fluidic pinball experiment

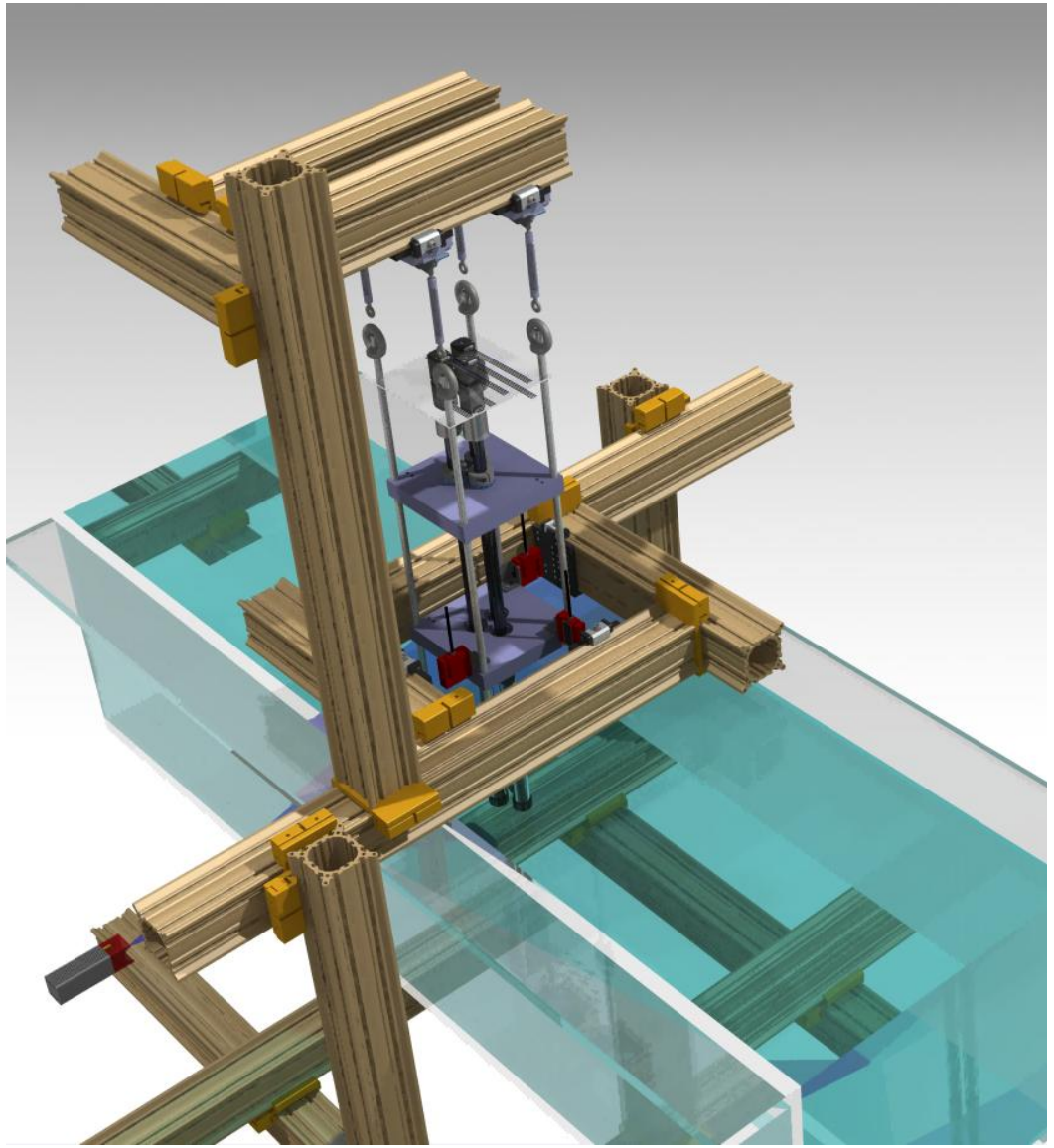
Synchronized measurements

Reconstruct feature space

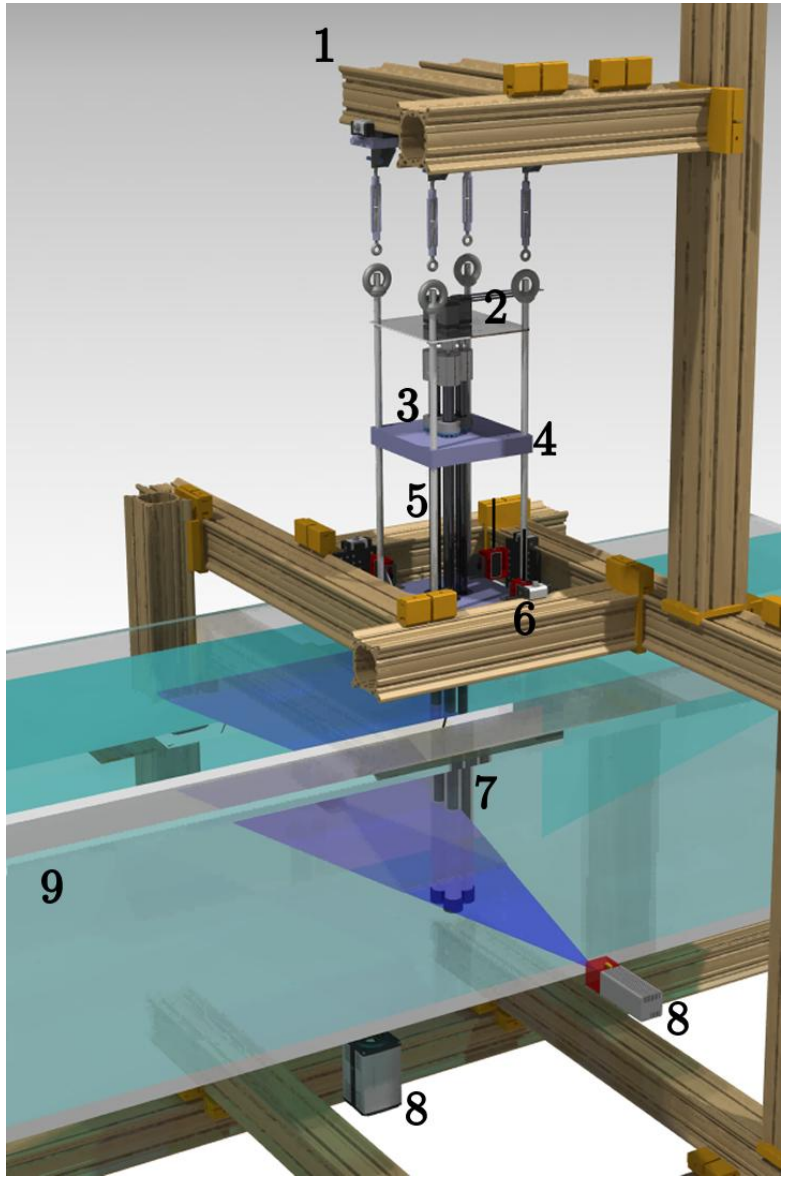
$$\mathbf{q} = \begin{bmatrix} C_l(t) \\ C_l(t-\tau) \\ C_d(t) \end{bmatrix} \simeq \begin{bmatrix} \gamma_1 \\ \gamma_2 \\ \gamma_3 \end{bmatrix}$$

Force measurements

Low-dimensional coordinates from snapshot velocity field data



Fluidic pinball experiment



1. Beam structure for supporting the experiment
2. Stepper motors for actuating the cylinders
3. Bearing configuration for blocking displacement
4. Supporting plates for ensuring alignment
5. Aligning metallic bars for robustness
6. Load cells for measuring forces
7. Fluidic pinball configuration inside water
8. PIV configuration. Laser for illuminating particles and camera for capturing particles displacement
9. Water tunnel test section

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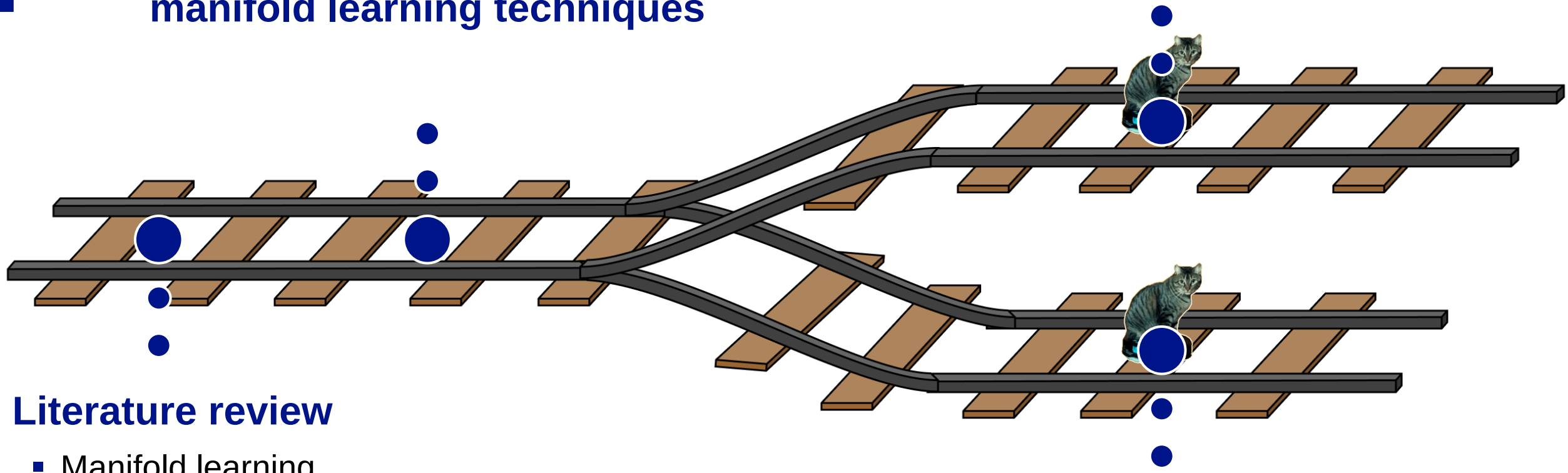

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Conference contributions

- **2nd International Conference on Mathematical Modelling in Mechanics and Engineering**. September 12-14, 2024, Belgrade, Serbia
- **APS Division of Fluid Dynamics Annual Meeting 2024.** November 24-26, 2024, Salt Lake City, UT, USA
- **EuroMech Colloquium on Data-Driven Fluid dynamics and 2nd ERCOFTAC Workshop on Machine Learning for Fluid Dynamics.** April 2-4, 2025, London, United Kingdom
- **1st International Symposium AI and Fluid Mechanics.** May 27-30, 2025, Chania, Greece.

Courses attended

- **Particle Image Velocimetry.** Von Karman Institute. December 2-5, 2024, Brussels, Belgium.
- **WG3/WG4 Meeting – Workshop: Machine Learning for Complex flows**. CYPHER. February 6-7, Madrid, Spain

Dissemination activities

- *Descubriendo patrones desconocidos en la turbulencia: secretos detrás de los datos.* **Noche Europea de los Investigadores 2024.** September 27, 2024.
- *¿En qué se parece un globo a un motor de avión? Descubre la magia de un aerorreactor.* **Semana de la Ciencia 2024.** November 14, 2024.

Pimienta’s blessings

Thank you for your attention!

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